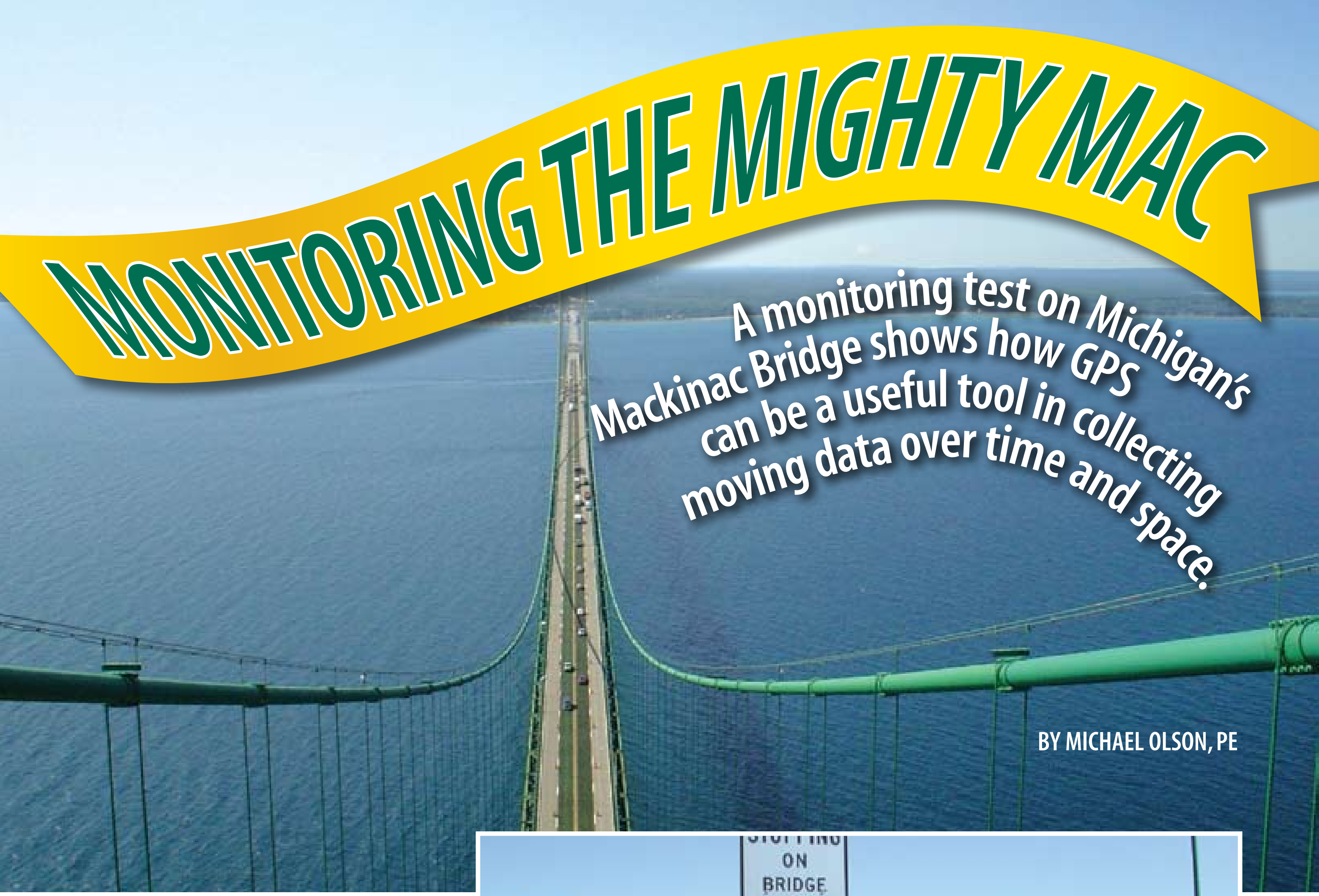
MONITORING THE MIGHTY MAC

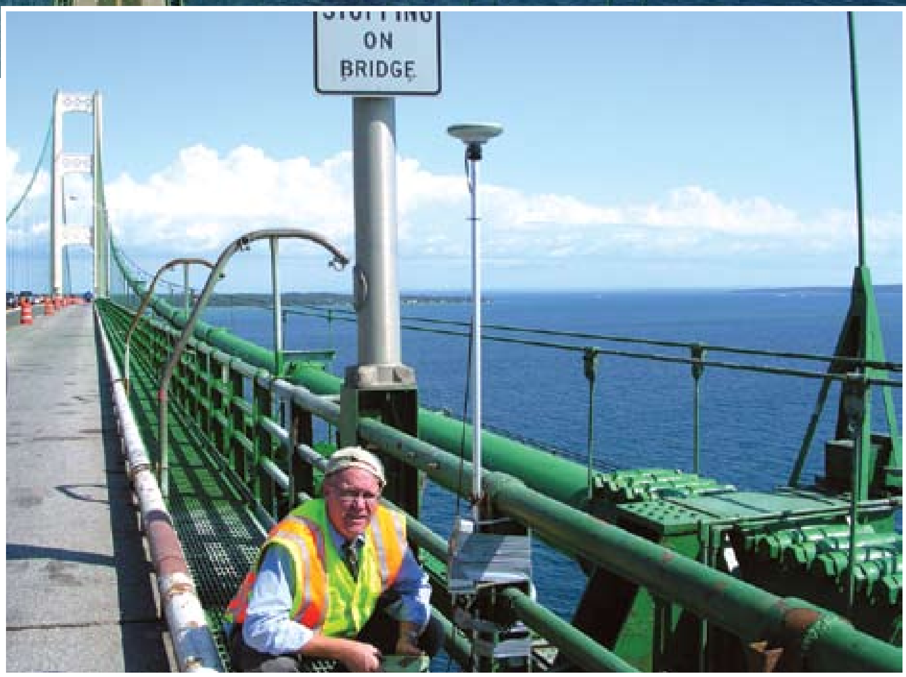


A monitoring test on Michigan's Mackinac Bridge shows how GPS can be a useful tool in collecting moving data over time and space.

BY MICHAEL OLSON, PE

In light of the tragedy that stemmed from the collapse of the I-35W bridge in Minneapolis/St. Paul, there is a growing awareness of the age and safety of our nation's bridges. The seemingly simple question, "Is the bridge I drive across every day safe?" represents many more complex questions. Is a given bridge structurally sound? Who makes that assessment? And are they using the best tools available to make this assessment?

In the spring of 2005, this last question was asked about Michigan's well-known Mackinac Bridge. The staff of the Michigan Department of Transportation (MDOT)/Design Survey Section, the Mackinac Bridge Authority (MBA), positioning manufacturer Leica Geosystems Inc. (Norcross, Ga.) and provider of monitoring infrastructure General Positioning LLC (Roeland Park, Kan.) more formally asked, "Can a system be designed that would be operational all day, every day to provide automatic information in the event of a structural change?" The multi-member team set out to design a test system based on solid geodesy that could be a fundamental model for similar structures everywhere.



Prior to 1998, the five-mile-long Mackinac Bridge between the Upper and Lower Peninsulas of Michigan was the longest suspension bridge in the world. Dr. Richard Sauve, Michigan technical sales representative for Leica Geosystems Inc., inspects a Leica GX1230 receiver at the mid-span of the Bridge.

Fulfilling a Need

Prior to 1998, the Mackinac Bridge between the Upper and Lower Peninsulas of Michigan was the longest suspension bridge in the world. Before opening in

November 1957, the only way to make passage between Mackinac City in the south and St. Ignace in the north was via a 45-minute ferry trip. During peak times, such as Michigan's white-tailed deer season, the ferry wait could be as long as 20 hours. In addition to the inconvenience, the effect on commerce was extreme in transit costs and time delays. Since the only other viable route was to traverse around Lake Michigan to the west through Chicago and then to points east, a bridge across the Straights of Michigan was considered to be a capstone project for future development, as well as exploitation of the state's upper peninsula.

In May 1954, construction of the five-mile Mighty Mac began. At its mid-span, the roadway stretched 199 feet high above water and the two main towers stretched 552 feet above water. A total of 42,000 miles of wire spanned the main cables and 1,016,600 steel bolts fastened the massive artery.

In any context, a bridge construction project of this type today would not be considered huge. But in the 1950s, before the advent of computers and advanced surveying and engineering technology, the design and construction of the largest suspended bridge was enormous. In 1950, Michigan's Governor G. Mennen "Soapy" Williams formed the Mackinac Bridge Authority (MBA) to oversee the design and construction of the massive bridge, and the suspension bridge was opened to traffic on Nov. 1, 1957.

Effects of Time

In its 50th year, the Mackinac Bridge remains an amazing sight, and a safe and convenient route between the Lower and Upper Peninsulas of Michigan, thanks to the ongoing maintenance and diligence of the MBA. But time is never forgiving, and maintaining or even improving the safety of the bridge continues to be a fundamental task. By definition, all suspension bridges are designed to move from temperature changes and wind, so the real question after 50 years is, "What is considered 'normal' or 'good' movement?" This is what MDOT and the MBA needed to find out.

Two receivers on either side of the bridge served as static bases and logged many weeks of continuous one-second data using 1 gigabyte Compact Flash cards.

"We are extremely lucky here in Michigan to have the longest suspension bridge in the Western Hemisphere," says Brian Dollman-Jersey, supervising surveyor for the MDOT Design Survey Section. "The purpose of monitoring the Mackinac Bridge is to get a solid mathematical representation of its natural movement while it is still relatively young and in good health. Once the bridge has been mathematically modeled, it can be observed over time and space to ensure that the bridge is acting as it was originally designed."

To monitor the motions of the "Mighty Mac" as it is known, six Leica Geosystems GX1230 GPS receivers were positioned on and near the bridge. Two receivers were positioned atop the two primary bridge towers and two receivers were located on the mid-span. The other two receivers were placed on solid ground (one on the St. Ignace side and one on the Mackinac City side) to serve as static bases. The high-precision receivers can log many weeks of continuous one-second data using 1 gigabyte Compact Flash cards. Data for this test was collected every second for eight days.

The four strategic locations for the receivers were chosen so as to best measure daily repeated motions from expansion and contraction due to winds that are regularly present on the Straights of Mackinac. Due to the five-mile length of the bridge, GPS is currently the only technology capable of measuring absolute positioning in real-time to the accuracy necessary to procure the measurements required for the mathematical modeling of the bridge. Data was stored locally on high-capacity Compact Flash cards on each of the Leica receivers, enabling eight full days of one-second data to be recorded.

"MDOT has a great deal of experience with these receivers, and since the units had to be placed in the open areas of the bridge and exposed to extreme conditions, ruggedness was a major factor in deciding the type of equipment to be placed on the bridge," says Andrew Semenchuk, administrator of the Michigan Spatial Reference Network

One of six Leica GPS receivers was positioned atop the north tower for the monitoring test.

(MSRN), MDOT Design Survey Section. "After the receivers were mobilized and the data collection phase of the operation underway, we were all excited to see how the data would be captured and analyzed."

The Parts and the Sum

Upon recovery of the six receivers after the test was completed, data was backed up and delivered to General Positioning LLC, a company with more than 10 years of experience related to monitoring work. The firm processed the GPS data using PAGERS, a modified version of the National Geodetic Survey (NGS) PAGES software. PAGES computes the precise Navstar satellite orbits and processes OPUS (Online Positioning User Service) data; developed by General Positioning LLC, PAGERS is specifically designed for monitoring civil construction work such as that done on bridges, dams and buildings. PAGERS software simultaneously processes kinematic (moving) and static GPS data to solve in real-time or post processes the status of the moving antennae of interest. When integrated with additional General Positioning LLC Web-based software, PAGERS can provide critical data to potential dangerous situations and assist in rapid assessment in the event that one has occurred. Further, when routine maintenance has been performed on a structure such as a bridge, engineers can evaluate the effect of the changes with regards to the "normal" bridge movement.

Meteorological data for this experiment, such as wind speed and direction and temperature, were taken from the Sault Ste. Marie Automated Surface Observing Site collectively operated by the National Weather Service, the Federal Aviation Administration and the Department of Defense.

The GPS results revealed that movement of the towers and bridge deck span strongly correlated to changes in temperature and wind. With a wind speed of 13 mph, the bridge deck moved in excess of 3 feet. The results also show the bridge deck sagging as it warms and expands with the air temperature, and similarly, the motions of the towers as the entire bridge warms and cools or as the deck swings with the wind. Such observations are valuable for ongoing maintenance and are essential for modeling the motions of any bridge. They also demonstrated that GPS technology is reliable and easily adaptable for continuous real-time or near real-time, hands-off operation.

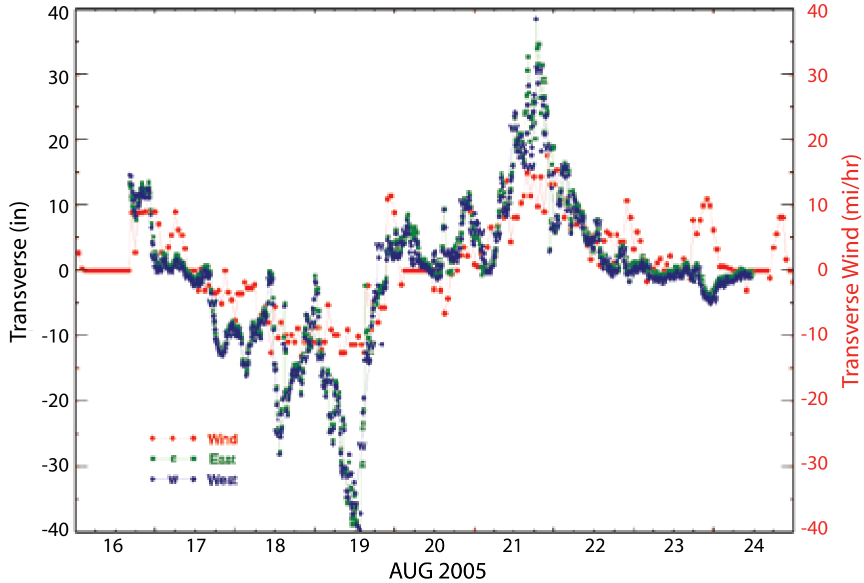
Supporting a Marvel

At this time, the state of Michigan is researching the implementation of a study on how best to monitor the Mighty Mac regularly. If and when a plan is implemented, it will most probably include GPS as well as real-time connectivity to the Michigan Spatial Reference Network and its 83 existing CORS stations.

"The purpose of this study was to determine the current technology and methods of monitoring such a structure," Semenchuck says. "The excellent results of the GPS observations made on the bridge were beyond the expectations of all involved."

"We are very excited to consider the possibility that we will be able to remotely monitor the bridge's behavior as it goes though

MDOT personnel Brian Fish, Keith Schultz and Jason Knauff provide monitoring help on the Mackinac Bridge atop the south tower.



The GPS results revealed that movement of the towers and bridge deck span strongly correlated to changes in temperature and wind. The estimated minus a priori, transverse coordinate differences for the east deck are shown in green and for the west deck in blue. The transverse wind speed is shown in red.

changes in temperature, wind events and loading from traffic and construction equipment," says Kim Nowack, PE, chief engineer for the Mackinac Bridge Authority. "GPS units strategically placed on the bridge will be a big part of our total health monitoring game plan."

Structural modeling of bridges, dams and buildings is critical to understanding how such structures behave over time, and to provide guidance to bridge engineers and geodesists on issues related to the structure's health and preventative maintenance.

Integration of sensors such as accelerometers, tilt-meters, seismographs, cameras and video cameras, strain gauges, optical measurement devices, RF-measurement devices, total stations and meteorological instruments can only augment the robustness of researchers' toolboxes.

The positioning capabilities of a high-precision monitoring system such as the one used on the Mighty Mac will ensure both the health of the structure as well as the security and safety of the general public. The monitoring undergone on the Mackinac Bridge resulted in detailed information that will help to ensure its longevity for generations to come. When public safety is top priority, an ounce of prevention is worth more than a pound of cure.

Michael A. Olson, PE, is president of Abletech Inc., a company specializing in high-precision monumentation for reference stations, engineered monumentation for NGS height monitoring and consulting engineering.